International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 961–972

PERFORMANCE EVALUATION OF ABSORPTION REFRIGERATION SYSTEMS USING INTELLIGENT OPTIMIZATION TECHNIQUES: A REVIEW

RAVINDRA KANNOJIYA[1] & RAJESH KUMAR[2]

[1]*Research Scholar, Department of Mechanical Engineering, Delhi Technological University, Delhi, India*

[2]*Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi, India*

ABSTRACT

Absorption refrigeration technologies have developed to provide enormous contribution to the industrial as well as residential applications. Providing cooling by utilization of renewable energy mediums as low grade heat and many others, are of utmost importance to the sustainable energy needs and surrounding preserving approach. This study provides an approach of different absorption refrigerating methods and the course of their development from the perspective of thermodynamics and economics. Theoretical and actual use for refrigerating machines with various pairs of working substances assisted by limited as well as new energy with recent advances are included in the present work. Thermally powered refrigeration technologies are not only dependent on nature of energy source but also on cost of the components during their operation and maintenance. Exergetic efficiency, exergy destruction, COP, ECOP and such other characteristics are the essential parameters which need to be synchronized with cost. To deal with these multiple objectives, optimization of the refrigeration systems becomes significant for better utilization of the sources. Many researchers have presented the ways for analyzing the performance through evolutionary algorithms as well as thermo-economic methodologies. The use of cumbersome mathematical and numerical techniques is always not feasible to provide better performance. The work presented here attempts to encourage the use of intelligent optimization techniques for analysis of performance characteristics.

KEYWORDS: Absorption Refrigeration, Evolutionary Algorithms, Exergy, Optimization & Renewable Energy

Received: Jul 12, 2019; **Accepted**: Aug 06, 2019; **Published**: Sep 25, 2019; **Paper Id**.: IJMPERDOCT201985

Original Article

1. INTRODUCTION

The modern trends of global world energy consumption imply that dependency on the conventional resources of energy is not enduring and also require environmental control from contaminating elements. The utilization of other sources of energy like wind, energy from Sun, from bio-degradable substances, geothermal and other non-conventional sources can be of utmost importance in the development of advanced machines that may fulfill the energy needs globally. The absorption refrigeration systems work on the heat-driven input. The heat can be given to the system either by conventional sources or renewable energy sources. The encouragement provided by the effort to protect atmosphere and ozone layer, researchers are trying to reduce the pollution effects. Global warming takes place when emissions from the combustion of oil, natural gas, coal and other gases, and other conventional sources chlorofluorocarbons, hydro-chlorofluorocarbons and water vapor, gets accommodated in the ecosystem. Refrigeration industry is taking care of the adverse effect on the environment. In Europe, the protocol is followed for the air conditioning systems in vehicles. Checking and remedies are needed for all refrigerating machines and other thermal systems if the protocol gets violated. Less consumption of energy for refrigeration cannot only be achieved only relying on efficient use of working fluids which are vital for solar refrigerating setup. Taking into

consideration that cooling requirements are very high with the rise in intensity of radiation, solar refrigeration has been of importance which gives an option for cooling. Solar operated absorption refrigerating systems have various configurations with different refrigerant-absorbent elements. The modern scenario requires energy sustainability of the thermal systems for all major applications. For rural areas, an NH_3-H_2O system was observed experimentally using sun as source of input but problem of leakage occurred in various components [1]. This situation required improvement in design as well as analysis for further research. The performance of the system was poor and it needed to be improved at the prototype stage. In the commercial spectrum of refrigeration systems, experimentation has been conducted with natural gas as energy input [2]. In the various components with respect to temperature of water, responses have been collected and heat interactions in the entire cycle provided the improvements which can be kept in the design. The major finding of this work was that for a low energy input the required cooling will also be less. The changes in absorbent configuration can provide better cooling effect as compared to conventional system of absorbents in absorption refrigeration. It was observed that mixture of LiBr and potassium formate provided better results [3]. The comparison has been made with the help of a program and also that less energy input required in the generator. Cost was another parameter which can be considered here for fabrication purpose. Heat source temperature has significant effect on COP and energy utilization. Study on single effect LiBr-H_2O absorption refrigeration provided that when temperature of source increases it affects the heating and cooling performance in a better way [4]. The effect of component temperature has not been taken into account for analysis. Energy utilization capacity shows slightly decreasing performance characteristics in this study for both applications. Energy analysis approach for absorption refrigeration uses the effect of temperature of components and circulation rate for measuring a desired COP [5]. Single effect as well as double effect systems have been analysed, and it was found that COP of both decides different application for their use in industry. Observation suggested that COP of double-effect absorption system has higher value. While exergy approach shows that thermal systems by variation of few parameters produced some different aspect of energy sustainability. Computational model of a single-effect LiBr-H_2O system has been developed with exergy calculations [6]. The relation between temperatures of components been determined and it was found that generator produces high exergy loss on certain situations. Performance of the said arrangement dependent on value sets of component temperatures. The other observation was that the generator deals with energy input and is most vital part of the system. Air-conditioning systems can also be analysed by exergy methods. An exergy approach implemented on air-conditioning system provided the optimization [7]. Decision making multi-objective techniques has been used in this research which works on an algorithm. The results of this process help with economic as well as product output optimal solution. In addition to this, emphasis on intelligent optimization techniques also increased showing reliability. Entropy generation method is also another way to provide user friendly design of the system. A single effect system has been taken for cooling load calculations where the evaporator and condenser temperatures are 4^oC and 38^oC and the generator temperature is 90^oC [8]. The values of effectiveness and efficiency for heat exchanger and pump are also of importance. The results show that entropy generation within the components regulates the behavior of system. The addition in exergy method provides the avoidable and unavoidable parts of exergy. An absorption system has been taken by using this concept which deals with exergy destruction [9]. The segregation of exergy components provides that there can be improvement in each component of the machine. This information was not available earlier in the analysis. A double effect machine taken for analysis based on exergy using LiBr and water as working fluids [10]. The performance show that both the generators have temperature dependency on each other and the exergy loss is highest in absorber and high pressure generator. This designates generator significant component of absorption cycle. Comparison has been made between systems on the basis of energy balances and thermodynamic properties investigated by developing a program [11]. The results of the analysis show

that condenser and evaporator works for an optimum value set of generator condition as well as provide the exergy relation of both systems. The results also show that exergetic efficiency has very less margin between them. This study further provides the way for optimization of the thermal systems. Irreversibility is one of the major causes of exergy losses in thermal system. Parametric study of absorption cycle shows that exergetic performance of the multi-effect systems depends on temperature setting of the components [12]. The research shows irreversibility is appreciable in absorber for both the systems. COP of both the systems gets affected by losses in all the components. A Mathematical model has been developed for NH_3 and sodium thiocynate using laws of thermodynamics for cooling as well as heating [13]. Exergy analysis conducted for the system and it was concluded that heat rejection and input in various parts of the system give performance variation with respect to temperature levels. Performance in both applications provides different aspect as well. Crystallization problem in the absorption cycle has been investigated by developing a computational method in various configurations [14]. The capacity of these systems has been kept same throughout the cycle. The observation has been made that risk of crystallization is less in series flow network. On the other hand, parallel and reverse pattern has more chance of this problem taking place. EES code has been developed for diffusion absorption cycle using NH3-H2O configuration [15]. The findings of this simulation provide that the concentration of 0.35 of ammonia rich solution is best. Exergy losses were also observed in different components and validation has been done. Simulation results also provide the scope for optimizing the working conditions. Temperature relations among components establish that findings help in more structured design. Use of waste heat in combined cycle for absorption systems has been carried out for other working fluids as well [16]. Measurement of irreversibilities in various components has been determined in their work. It was estimated that cogeneration cycle provides better performance characteristics. The useful energy output potential is less as compared to exergy destruction taking place within the system. This on the other hand provides that optimization need is there for thermal behavior of the system.

2. ABSORPTION REFRIGERATION

Absorption refrigeration frequently provides for solar refrigeration. It requires low grade energy input and, providing the same capacity, the size of an absorption chiller is relatively smaller than adsorption refrigerating machines due to higher value of transfer of heat rates of absorbent in the chemical process [17]. The systems that have been used are having LiBr-H_2O and aqua-ammonia as working fluids. They can be made to work as multi-effect systems with the wide range of temperature varying gradually. Other organic fluids as well as refrigerants also have vital roles depending upon their implication to the industry and households. Observations on design and optimization of LiBr-H_2O cycle has been carried out for thermal system considerations providing sustainable energy methods [18]. The finding was that generator governs the capacity of cooling and heating applications. Cost is also one of the parameter which needs to be considered. The problem of crystallization should also be taken care of while it is in operation. This factor requires special attention from the design point of view. For resolving this problem concentration range should be set accordingly.

3. LIBR-H_2O ABSORPTION WITHOUT EJECTOR

Few researchers have conducted analysis taking into consideration the part which cannot be avoided for various cycles in this configuration [19]. They have observed various performance characteristics and the effect of temperature. The performance of triple effect is better than double lift systems. It has been studied that various chillers with combination of collectors of different configuration provide simulation of systems, with single or multi-effect and collectors [20]. Comparison has been made to double lift machines, appreciable savings observed to be appreciable as 39% results as for the combination of single lift machine and the collector. It is observed that double effect system with the thermodynamic as

well as thermo-economic analysis and also performed the optimization of it [21]. They have the heat source as steam which comes from energy resource. A cost minimization methodology based on the thermodynamics and economics combination concept is applied for calculating cost factors of input and output of system using cost reduction criteria. The system is again checked to find the significance of several variables on component costs and other important components. Researchers have performed the exergetic analysis technique on a solar operated double-effect absorption LiBr-H_2O system [22]. The analysis has been done to form the rational basis of the potential that a system possesses. Also, they have shown that better evaporator quality give better performance. Analysis have the coupling of single lift LiBr-H_2O cycle and CO_2 operated compression cycle for high electronics applications and for space conditioning [23]. A thermodynamic model has also observed the cascade system characteristics, and analysis was carried out to find out the system performance under various operating conditions. Availability analysis carried out for determination of irreversibility within system components providing condenser and absorber temperature 87.8^{o}C and 140.6^{o}C respectively in both the systems. [24]. Investigation on the system components in cooling mode through cycle simulation has been carried out by researchers. They described the system behavior characteristics in relation with inlet temperature of air to the absorber, concentration, the solution distribution ratio[25]. Observed critical value of the thermodynamic aspects can be maximized. This observation provides the required criteria for the design of future thermal systems.

4. LIBR-H_2O ABSORPTION WITH EJECTOR ASSEMBLY

It is observed that combining the LiBr-H_2O system with combined power and ejector based cycle having R141b as working fluid provides different aspect [26]. They have performed the exergy analysis to observe the cycle efficiency. It is shown that the at a particular temperature range single and double effect cycles operates and temperature range is higher for double-effect systems [27]. They have also shown a 30% increase of performance in terms of COP in comparison to conventional cycle. It has been analyzed that thermal system having micro-turbine as power source on the basis of balance equations has different nature [28]. It is provided from results that integrated system is efficient and less energy consumer than other conventional systems. For energy saving the favorable system is that which uses two stage compression chiller providing intercooling and sub-cooling as well.

5. AQUA-AMMONIA ABSORPTION SYSTEMS

Researchers have taken the case of Saudi Arabia, where electricity consumption is much higher for the purpose of refrigeration and air-conditioning [29]. It is tested and found that their work by consuming solar energy to provide energy for such systems will conserve large amount of energy that can be used for other influential sector. The design is for 24 hr operation of absorption refrigerating systems. Study on thermal system show that coefficient of performance, mass flow rates behaves according to heat interactions taking place within the system. It is shown that COP and work done are dependent on component temperature values and on chemical nature of the solution [30]. Aqua-ammonia absorption refrigeration system has been studied on the basis of second law and exergy loss of each component, ECOP, COP and other parameters have been found. Exergy losses change in the system components [31].

6. AQUA-AMMONIA ABSORPTION WITHOUT EJECTOR

Comparison of the results with experimental and some manufacturer data reported in the literature [32]. They have analyzed performance characteristics of various components on the basis of energy and mass conservation. They have found appreciable closeness in the results. Results obtained for this analysis shows deviation. Efficient performance of the

separating component is of importance. Work have been conducted for the analysis on an intermittent operation of refrigerating system and evaluated with various other mixtures [33]. It was mentioned that while using ternary mixture the performance rating can be much higher. It has been proposed for a different system for modelling and its simulation and considered the role of gravity in it [34]. The pump was specially designed to deal with the certain parameters. The flow conditions also improved by researchers using valves configuration. The leakage issue also taken care of for better results in various capacities. It has been proposed that a novel cycle using combination of expansion and compression has value for thermal systems [35]. Performance of this cycle is much higher than that of the usual cycle providing higher efficiency. Pump can provide work for advancement of the cycle in other ways also. Research work have provided the work on ammonia-water system and also provided the costing analysis of the system [36]. They have also emphasized on the optimization of various parameters. The variables were selected to provide cooling capacity at the economic scale. A detailed mathematical analysis was carried out in their work. Scientists have taken large scale heat-driven absorption cooling system that is available in the marketplace for industrial applications but the concept of a solar driven absorption chiller for air-conditioning applications is relatively new [37]. Absorption chillers have a lower efficiency than compression refrigeration systems, when used for small scale applications and this restrains the absorption cooling system from air conditioning applications in residential buildings. They have emphasize on the potential of a solar driven ammonia-water absorption chiller for residential air conditioning application. They have developed a thermodynamic model based on a 10 kW air cooled ammonia-water absorption chiller driven by solar thermal energy. They have conducted both energy and exergy analyses to observe the performance of this residential scale cooling system. The analyses shows that absorber is where the most exergy loss occurs (63%) followed by the generator (13%) and the condenser (11%).

7. AQUA-AMMONIA ABSORPTION WITH EJECTOR

It is observed that energy input can be provided by using solar energy but there is a limitation on the source temperature criteria which can affect the overall performance of the cycle [38]. The condensation part can also be controlled by using these considerations. The solar components can give better and efficient results through this and the COP will increase due to this. The modifications in the design provided the combination of absorber and ejector. This change in design has also improved the cooling in the setup where flash tank and other components were installed. They have developed a simulation program to evaluate the modified combined cycle using aqua-ammonia refrigerant. The comparison of the proposed combined cycle with conventional cycle shows improvement in the performance.

8. AQUA-AMMONIA IN CASCADE & SPACE CONDITIONING

Recent works have provided a different approach using hybrid refrigerator running on waste heat with a binary mixture as working fluid [39]. It consists of heat-driven compression refrigeration and an absorption refrigeration subsystem. They share the same condenser and evaporator. Mid-temperature waste heat is used in the power and compression refrigeration subsystem to compress ammonia vapor. The low-temperature waste heat is used in the absorption refrigeration subsystem to preheat the strong solution before entering the rectifier. The exhaust vapor from the ammonia–steam turbine is introduced into the rectifier of the absorption refrigeration subsystem to generate pure ammonia. The new system exhibits superior performance because of the cascade use of waste heat in the two subsystems. Few studies show that a triple effect cycle with ammonia-water as working fluids has other potential [40]. They have investigated a triple effect absorption heat pump using simulation. Ammonia-water solution used as the working fluid for the high pressure cycle, ammonia-water and ammonia-sodium thiocyanate solutions investigated for the lower pressure cycle. The overall system is so configured that

the absorber, condenser and rectifier heat duty from the high pressure cycle is rejected to the generator of the low pressure cycle. The complete absorption system has been analyzed. Cycle performance was modeled over a wide range of cooling and heating mode to determine the overall advantages. It can provide better opportunities for future aspects.

9. HYBRID REFRIGERATION SYSTEMS

These systems works on compression as well as absorption technique. Mechanical work and solution circuit both play a vital role here. The solution cycle performs absorption and desorption of the refrigerant present in the system. These systems provide a bridge between traditional compression and absorption cycles. The hybrid cycle uses mixture of refrigerants as absorbent and other as desorbent. This arrangement provides wide range of temperatures available for the system to perform for a mixture. The volatile nature of the refrigerants plays a vital role for the analysis. The irreversibility associated with the system also gets reduced in the heat interaction process among components. Analysis on heat pump cycle as well as on solution cycle has been performed in two stages of each [41]. The results show that there is a significant increase in the COP as compared to R-22 only. The other aspect of the analysis emphasized on energy saving and balance in pressure conditions in a traditional way of refrigeration cycle. Another work on successive substitution approach investigated that heat interaction among components provides COP measure [42]. The results show that COP has been increased and also the pressure balance condition restored in comparison to earlier traditional systems. Analysis of overall heat interaction and its behavior in all components has been performed by simulation model [43]. The observations were made for the mass flow of ammonia and water pair using experimentation. The design and analysis of the system provided the better criteria for future optimization approach in terms of energy saving. Application of internal combustion engines to run the combined cycle has its observations. A study on hybrid cycle working on traditional fluids using compressor has been performed [44]. The drawback of this analysis is from the economic point of view. The system worked on pressure balance in all the components. The input parameters have not been considered in terms of temperature of external components. The internal behavior reflects the cycle performance and provides the way for further clarity towards optimization. Study on ammonia water absorption cycle in combination with compressor assembly provided optimization [45]. The process has been achieved by temperature gradient in the internal and external factors. Again the pressure balance and constant values for heat interaction process were assumed for equilibrium condition. The optima was found controlling the heat interaction among the components and it is observed that hybrid system is better for cooling applications considering external and internal relation. Ternary working fluid condition provides the relation among properties in a hybrid system [46]. The analysis on the basis of working fluid configuration is uncertain about property calculations of the solution. The intermittent operation of the hybrid systems provide higher COP [47]. The study shows that each and every system works better in terms of COP if the combined intermittent operation is to be carried out.

10. INTELLIGENT TECHNIQUES

It has been proposed that few techniques such as ANN model, fuzzy logic, fuzzy inference systems and other ways can be adopted for the simulation of various thermodynamic systems. The new formulation has been done to determine the COP and circulation factor. The other components have been used to create the network. Apart from that MATLAB and EES are the other simulation and solver methods respectively, which can provide complex relations to be solved easily. A refrigeration machine for optimization requires objective function which considers all the necessary parameters satisfying

multiple criteria as well. A machine assisted by cooling tower in a refrigeration method considered for optimization using cost and exergy destruction as objectives of analysis [48]. The criteria set taken as thermodynamic and economic condition. This has energy and exergy approach for thermodynamic part and total revenue requirement for economic part. In their analysis, comparison has been made for optimized systems. It was also observed that multi-objective design satisfy the general approach of engineering applications.

11. TLBO ALGORITHM IN THERMAL SYSTEMS

In recent works in the field of thermal engineering, optimization of different thermodynamic parameters by the meta-heuristic algorithms has been proposed by researchers. But, many of these algorithms can perform effectively when a set of tuning parameters is there and can be adjusted as per the requirements [49]. For these algorithms to perform best, optimized values of the tuning parameters are required which is more sophisticated in nature. Teaching-learning based optimization is less time consuming and provide better results. This is a parameter-less algorthim-specific technique to perform simulation. It can be tested for refrigeration systems considering cost and exergy parameters. The variety of applications has been considered in decision making problems using this algorthim.

12. GENETIC ALGORITHM

For the performance evaluation thermal systems, this algorithm can be used. The convergence rate of this is slow because it considers several parameters which control the algorithm. Due to this it can sometimes behave abruptly. However few researchers have conducted its application and found that the proper tuning of parameters can help in controlling the better results. This algorithm has been used by few researchers to optimize the system and has shown significant performance in this way.

13. TLBO FOR OPTIMIZATION OF SYSTEMS

Optimization of thermal as well as other systems require strategy to achieve certain set of values of different components for better results. Global optimization still remains one of the challenges due to the fact that it takes set of mathematical configurations for any system [50]. The benchmark functions were taken for the analysis, and results were drawn for the thermal system. Figure 1 shows that the algorithm works for decision makers for teacher-learner phase.

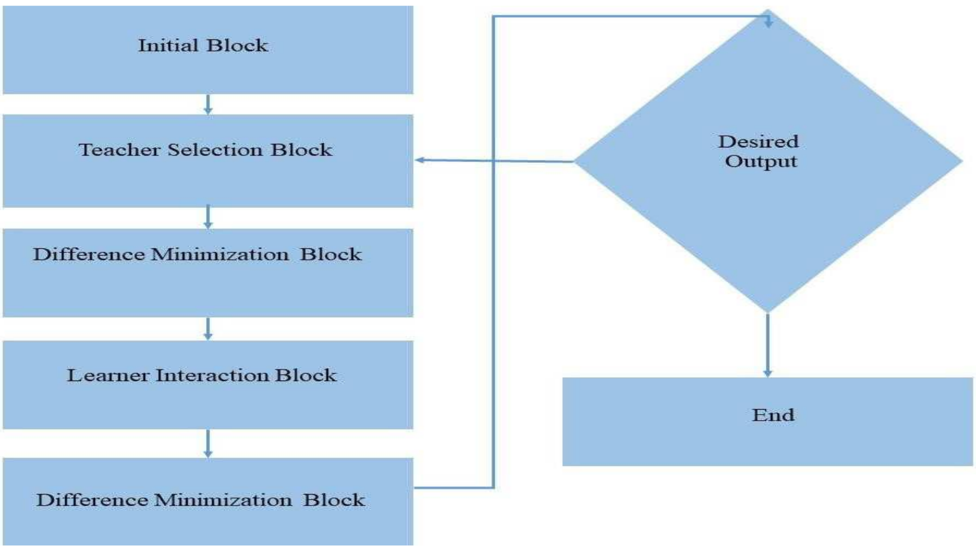

Figure 1: TLBO Flow Process[50].

There is also classification according to level of complexity for solving the multi-objective problem. The working of algorithm provides the idea about the simulation process and its progress step by step.

14. FUZZY INFERENCE SYSTEMS

Fuzzy logic is applicable to wide range of fields including artificial intelligence and smart controllers. It is a three-stage process, firstly all the input values are fuzzified, next fuzzy output is calculated using these inputs and finally the output is de-fuzzified in crisp output. Researchers have applied this technique for speed regulation of compressor in a refrigeration plant [51]. Fuzzy analysis for thermal systems has shown variety of results, which can be considered for further optimization process.

15. ARTIFICIAL NEURAL NETWORK

Neural network has certain layers which connect the various components of the refrigeration system, and then it is trained to provide necessary analysis [52]. It is performed on ammonia water refrigeration systems. There are various learning techniques for training different neural networks. The back-propagation algorithm is a technique which provides variants in a way that network can be trained according to the problem. Standard back-propagation is another way to train the network. It is dependent on the user's decision that which training algorithm will be suitable for his problem and the selection is done by checking the behavior of variants in each training technique. The simple analysis of thermodynamic system can be done by artificial neural network technique for regulation of frequency of different components. Neural networks provide the approach which simulates the various parameters and the results emphasize the use of the tool for optimization of complex problems. The mathematical model of complex thermal systems can be developed for better understanding of intelligent techniques. The relation can be built for the artificial intelligent atmosphere where control can be achieved for the system properties.

16. COMBINATION OF TECHNIQUES

It can be observed that few researchers have used Adaptive Neuro-fuzzy inference systems on thermal systems [53] and Fuzzy-TLBO on electrical systems [54]. The results of the combination techniques show promising approach. It can be observed that convergence time, tuning of parameters and achieving global optima form these techniques are of a better possibility.

17. CONCLUSIONS

- The solar assisted absorption refrigeration and cooling systems are the keys to supply the energy needs of the world. Renewable sources, waste heat etc. are the heat input while LiBr-H2O, aqua-ammonia, organic refrigerants etc. are the working fluid pairs with different combinations.
- In various countries which are having high requirement of energy cooling, solar operated absorption refrigeration machines with combined-ejector cycle or cascaded cycle may provide sound supply.
- The temperature range for single, double and triple-effect cycles vary because the temperature conditions at single-effect cannot drive double-effect cycle.
- The cost minimization methodology using thermo-economic concept helps to reduce the cost of the overall system. Further, optimization of the system or hybrid systems can be done by using various techniques.

- The simulation part of the absorption refrigeration and cooling systems can provide the way to solve the complex relations.
- The future energy needs will be fulfilled by the renewable energy sources using combined power for cooling and heating purposes.
- Economic point of view provides better understanding of thermal aspects as well for energy saving potential in a thermal system. It is of prime importance to deal with the cost factors.
- All the energy and exergy methods for determining the performance in addition to conventional losses is more vital thermodynamically.
- The main objective of the study is to understand the concept of avoidable and unavoidable losses in a thermal system.
- The environment of artificial intelligent techniques may provide better way to regulate the system behavior and the real time values can be obtained.
- The range of optimization can lead to global optima while training from local optima for thermal systems.

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